SF 298 MASTER COPY , KEEP THIS COPY FOR REPRODUCTION PURPOSES

REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
June 13, 1997

3. REPORT TYPE AND DATES COVERED
Final Technical Report

4. TITLE AND SUBTITLE
Light-Beem Technology: A local Probe of Metal Semiconductor Interfaces

5. FUNDING NUMBERS
DAAH04-95-1-0632

6. AUTHOR(S)
Dror Sarid

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(ES)
The University of Arizona
Optical Sciences Center
1630 E. University Blvd.
Tucson, Arizona 85721-0094

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
ARO 34720.1-MS

11. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12 b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Abstract: This final report describes an experimental system aimed studying a novel characterization method of metal-semiconductor interfaces which combines ballistic electron emission microscopy (BEEM) with optical excitations. The idea is that the spreading resistance, or space charge, associated with the ballistic electrons injected into the Schottky barrier by the tip of a scanning tunneling microscope (STM), can be modulated by optical excitation. The local photoresponse can therefore be mapped spatially across the barrier, below the metal electrode into which the STM is tunneling. The proposed technology will also enable one to directly measure the lifetime of the photoexcited carriers below the metal electrode, using short laser pulses at different wavelengths. The experimental system has been built, BEEM images acquired, and I(V) curved measured. Lack of sufficient funding led to the termination of the project.

14. SUBJECT TERMS
BEEM, Light BEEM, STM

15. NUMBER IF PAGES
7

16. PRICE CODE

17. SECURITY CLASSIFICATION OR REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

FINAL TECHNICAL REPORT

Schottky barriers, formed at metal-semiconductor interfaces, play an important role in electronic devices. In spite of their importance and the large effort invested in perfecting them, their detailed physical properties are still not fully understood. These complex regions are highly sensitive to the specific method of preparation, and to the concentration, distribution, and type of impurities in the semiconductor medium. The electronic properties of the barriers are usually obtained from the voltage-current and voltage-capacitance response which provide spatially averaged characteristics. However, the need for local characterization arises when one wishes to establish, for example, the local correlation between the barrier and morphology of the metal electrode, or defect and dopant concentration below the metal electrode. To that end, Kaiser et al. developed a novel characterization method, ballistic electron emission microscopy (BEEM), which proved to be a powerful tool to locally probe the properties of Schottky barriers just beneath the metal electrode. The technique utilizes a scanning tunneling microscope where electrons tunnel into the thin (10 nm) metal electrode of the Schottky barrier. The fine beam of the tunneling electrons, several nm in diameter, traverses the metal ballistically, part of it, i_r, is reflected back from the barrier into the metal electrode, and the other part, i_i, is injected into the bulk of the semiconductor, where it diffuses towards a collector electrode.

We have extended the BEEM technology to a Light-BEEM technology by incorporating optical excitations at the barrier region. Specifically, we have a beam of light incident through the partially transparent thin metal (gold) electrode. The illumination source was a laser diode coupled through a conducting optical fiber. Because of the large above-band-gap absorption, the photoexcited carriers will be confined to several hundred nm below the metal electrode, essentially flooding the barrier with electron-hole pairs. The carriers, whose lifetime is determined by the dopants and traps inside the barrier, generate a photovoltage that flattens the bent energy bands in the barriers. The flattening of the energy bands will therefore have the same lifetime as that of the photoexcited carriers. It is this flattening which is expected to modulate the BEEM current in our proposed experiments.

Specifically, the flow of the current i_i is made possible by the electric field inside the barrier (consider an n-type doping) which sweeps the electrons towards the bulk of the semiconductor, from where they diffuse to the collector electrode. The decrease of the electric field inside the barrier by the photoexcited carriers is therefore expected to decrease i_i and increase i_r, which can be measured by the collector electrode. To optimize the signal to noise ratio, one can first apply an optical excitation, next null the resulting photoinduced current by applying an external voltage, and then inject the BEEM electrons. Raster scanning the electron beam across a sample will therefore generate an image associated with the photoresponse of the barrier, just below the metal electrode. The image can be obtained using different excitation sources at different pulse widths and rates, thus providing information about the lifetime of the photoexcited carriers inside the Schottky barrier.

Figure 1 is a schematic diagram of the BEEM system where a conventional scanning tunneling microscope injects hot carriers into the Schottky barrier consisting of a 10 nm gold electrode deposited on an n-type silicon substrate. A collector electrode on the other side of the sample feeds a preamplifier with a picoamp sensitivity, which in turn feeds the second port of a Nanoscope-III

system. We have built the electronics required for this experiment, including a sub-pA current amplifier, and integrated it into a scanning tunneling microscope.

Figure 2 shows six BEEM images of a Au-Si interface at 0.8, 1, 1.1, 1.2, 1.3 and 1.4V applied between the tip and Au sample. The image shows local variations in the Schottky barrier height of the Si-Au interface. The Dark to light height indicates a BEEM current variation of 20 pA (first image) to 50 pA (last image).

The STM tip was then replaced with an Al-coated optical fiber whose end was pulled to have an aperture of the order of 50 nm. A HeNe beam was focused into the fiber which was lowered toward the sample by the STM electronics until a tunneling current was established. The BEEM current as a function of voltage with and without illumination was measured, and the results shown in Fig. 3. The BEEM current increased in the presence of illumination, as expected. A difficulty in carrying out the experiment involved the bending of the optical fiber as it was raster scanned across the surface. In contrast to near-field optical microscopy, where the tip is hovering above the surface, here the metal-coated fiber has to be in virtual contact with the surface to make tunneling possible. The drag force, therefore, was too high to make the imaging possible. With more funding, we would have used a different method of illumination which is less suceptible to drag forces. Under these conditions, the Nanoscope-III (Digital Instruments) could deliver two images obtained simultaneously, one showing the morphology of the metal electrode and the other the photoresponse of the Schottky barrier. At this point of the research we ran out of funding (about 20 k) and could not continue the experiment.

1. W. J. Kaiser and L. D. Bell, Phys. Rev. Lett. **60**, 1406 (1988).

2. L. D. Bell and W. J. Kaiser, Phys. Rev. Lett. **61**, 2368 (1988).

3. F. Flores and N. Garcia, Phys. Rev. B **30**, 2289 (1984).

4. G. F. A. van de Walle, H. van Kempen, P. Wyder, and P. Davidsson, Appl. Phys. Lett. **50**, 22 (1987).

5. L. D. Bell, W. J. Kaiser, M. H. Hecht, and L. C. Davis, in *Scanning Tunneling Microscopy Methods of Experimental Physics*, ed. by J. A. Stroscio, W. J. Kaiser, Academic Press (1993).

6. Roland Wiesendanger, *Scanning Probe Microscopy and Spectroscopy*, Cambridge University Press, (1994).

7. Dror Sarid, *Exploring Scanning Probe Microscopy with Mathematica*, Wiley Interscience, (1997).

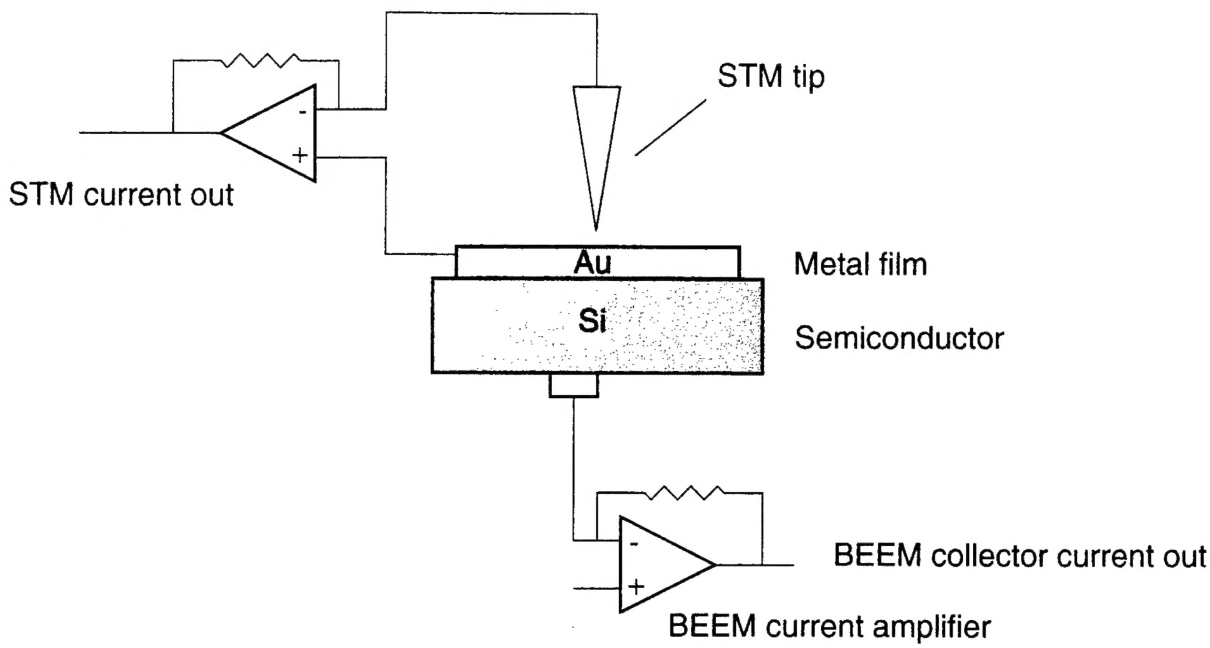

Fig. 1 Schematic of BEEM experiment.

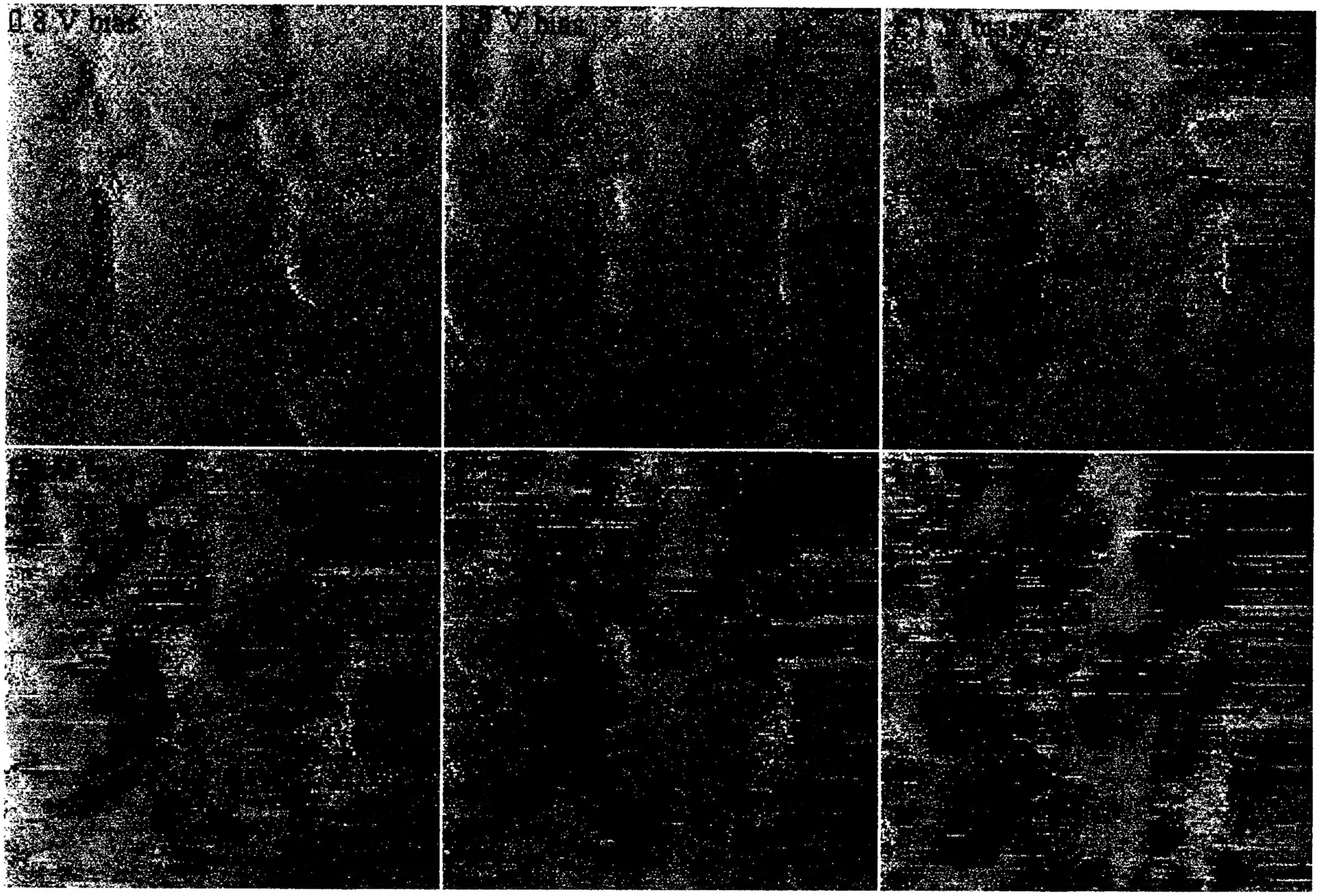

Fig. 2 BEEM images of Au-Si interface at several tip-Au bias voltages.

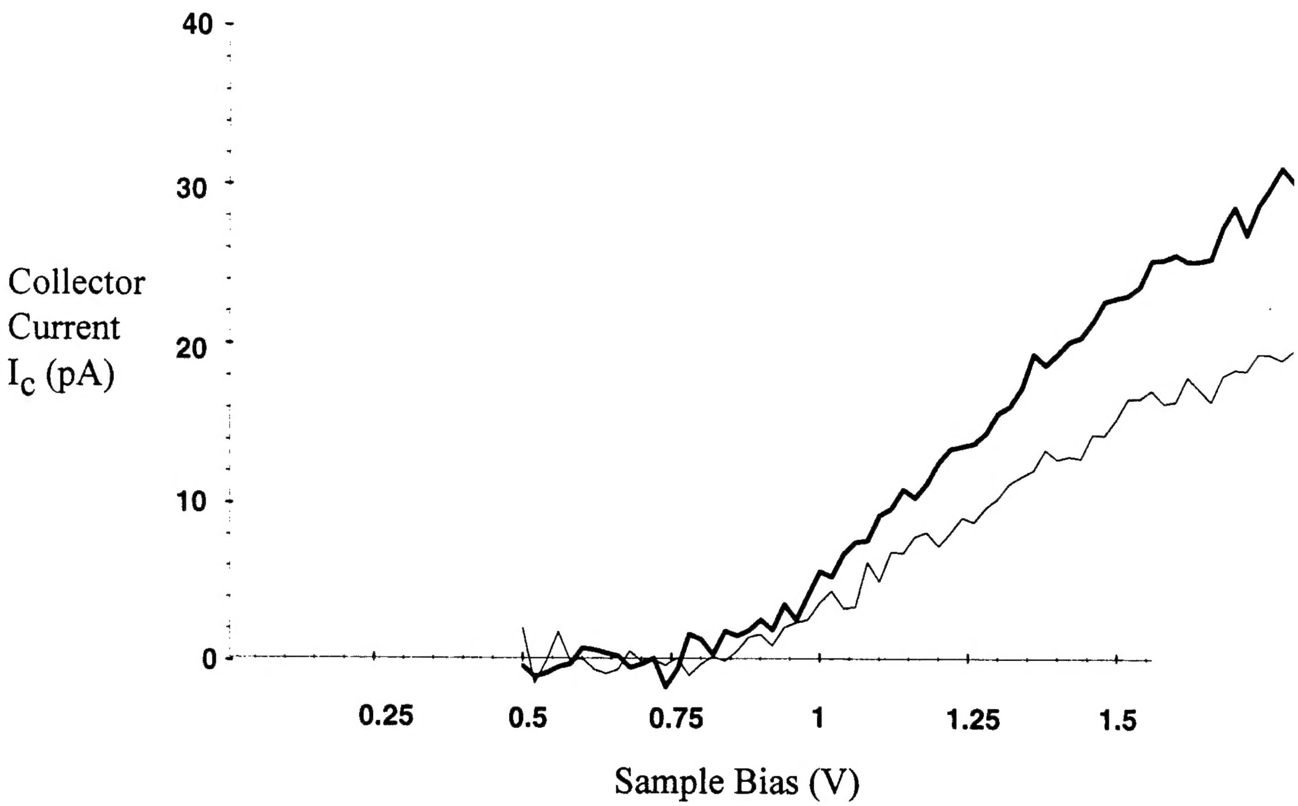

Fig. 3 I-V curve of BEEM current vs. Tip-Au bias with light (red) and without light (black).